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AN INVESTIGATION OF THE EFFECTS OF BOUNDARY CONSTRAINTS ON THE SOUND INSULATIONS OF LIGHTWEIGHT, DOUBLE LEAF PARTITIONS

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Summary

The sound insulation of a metal-framed, double leaf partition (measured in the Research Department Transmission Suite) was considerably lower when the two leaves of the partition were built into common, rather than independent, surrounding walls. The purpose of the work described in this Report was to investigate whether this shortfall in sound insulation was caused by the mechanical coupling of the two leaves of the partition at its perimeter.

To investigate the nature of any coupling between the two leaves, the vibration isolation was measured between the two leaves of the test partition, with the two leaves built into either common surrounding walls or into independent walls. Contour plots of the vibration isolation between the two leaves of the partition, for both boundary conditions, revealed the extent of the coupling at the perimeters of the leaves. The amount of coupling observed was sufficient to explain the differences in the sound insulation between the two conditions.

Index terms: *Sound; sound insulation; vibration isolation*

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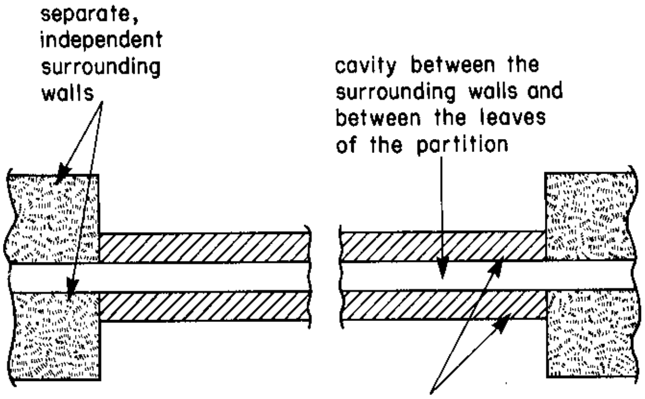
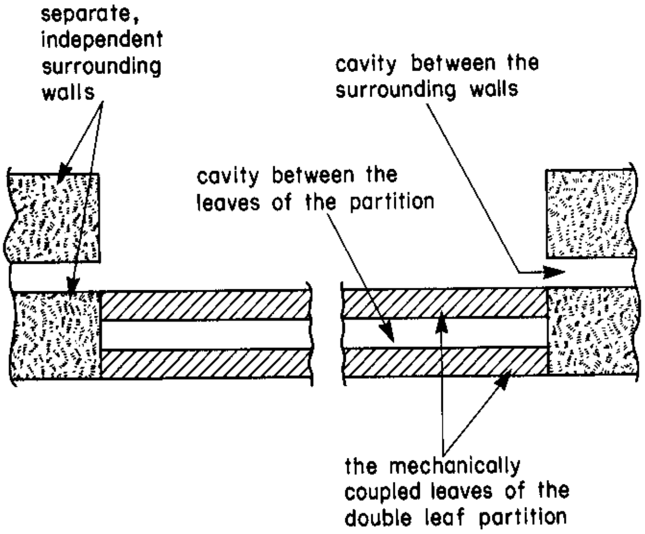
1. INTRODUCTION

A series of measurements of the airborne sound insulations of various metal-framed partitions has recently been made[1] in the Research Department Transmission Suite. One of the measurements concerned the sound insulation of a double leaf partition that had already been tested in a different Transmission Suite. The new measurement was intended as a reproducibility check between the two Transmission Suites.



(a) The two leaves of the partition built into independent surrounding walls.



(b) The two leaves of the partition built into common surrounding walls.

Fig. 1 - The two mounting conditions for the partition tests.

Unfortunately, the two measurements did not show close agreement; the Research Department measurement having a higher overall sound insulation. At the time, the differences between the two results were attributed to the different mounting conditions of the partition in the two tests. For the Research Department measurement, each leaf of the double leaf partition had been independently mounted in an independent surrounding wall. The two surrounding walls were mechanically well decoupled. For the measurement in the different Transmission Suite, the two leaves of the test partition had been mounted in common surrounding walls, so the two leaves were mechanically coupled at their perimeters. These two mounting conditions are shown in Fig. 1.

The British Standard, concerning the construction of Transmission Suites[2], makes the following comments and recommendations about flanking transmission, the partition mounting conditions and the prediction of the sound insulations of partitions in field sites from Transmission Suite measurements:

> In a Transmission Suite, there should be "... suppressed radiation from flanking elements" (i.e. sound that has not passed directly through the partition under test should be suppressed). The airborne sound insulations of the source and receive room walls must be sufficiently high, "... the radiation from flanking elements being reduced either by the use of heavy elements" (massive walls) "or by the use of appropriate [wall] linings". It does not matter into which of the Transmission Suite walls the test partition is built, (it may be "... connected to one or both of the test rooms ...", or it may be "... structurally isolated from both test rooms ..."), but the test partition should "... be installed in a manner as similar as possible to the field construction, with a careful simulation of normal connections and sealing conditions at the perimeter and at joints within the partition".

The sound insulation of the partition installed in a field site can be predicted only indirectly from Transmission Suite measurements; and only then if the mounting conditions in the Transmission Suite are similar to those in the field installation and if the level of flanking transmission of sound in the field site can be estimated. Measurements can be directly applied, provided that the flanking transmission is included.

For this purpose, a 'mock-up' can be constructed, in which the test rooms and the coupling of the test partition to the construction (with flanking paths included), must resemble the situation in the field site. Such a 'mock-up' does not fulfil the requirements of a Transmission Suite in which any flanking transmission of sound must be suppressed.

In the Research Department Transmission Suite, it is usual practice to measure the airborne sound insulations of double leaf partitions with each leaf built into an independent surrounding wall. This mounting condition simulates well the way in which double leaf partitions are typically used in BBC studio constructions, where particular care is taken to ensure that the leaves of the partitions are mechanically well decoupled.

2. AIRBORNE SOUND INSULATION MEASUREMENTS

It was necessary to determine the cause of the poor reproduciblity between the Research Department measurement and the measurement made in the different Transmission Suite; then to investigate further the nature of any coupling between the two leaves of the partition. In two separate experiments, the double leaf partition was rebuilt in the Research Department Transmission Suite, with the two leaves of the partition built either into independent surrounding walls (as in the previous Research Department Transmission Suite measurement), or into common surrounding walls. It was intended to investigate the extent of any mechanical coupling at the perimeters of the leaves of the partition, by measurement of the vibration isolation between the two leaves. It should then be possible to predict the effects of the mechanical coupling on the airborne sound insulation of the partition.

Fig. 2 shows various airborne sound insulation measurements made on the double leaf partition. The repeat measurement of the sound insulation of the partition, with its two leaves built into independent surrounding walls in the Research Department Transmission Suite, shows very good agreement with the original measurement, bearing in mind that the partition was completely rebuilt. A comparison of the sound insulation curves above 250 Hz, shows that the measurements, made in the different Transmission Suite (with two leaves of the test partition built into *common* surrounding walls), produce a curve **(a)** lying between the other curves; these other curves are for the leaves of the test partition which had been built in the Research Department Transmission Suite, firstly, in *common* surrounding walls **(b)**, and secondly, into *independent* surrounding walls **(c)** and **(d)**.

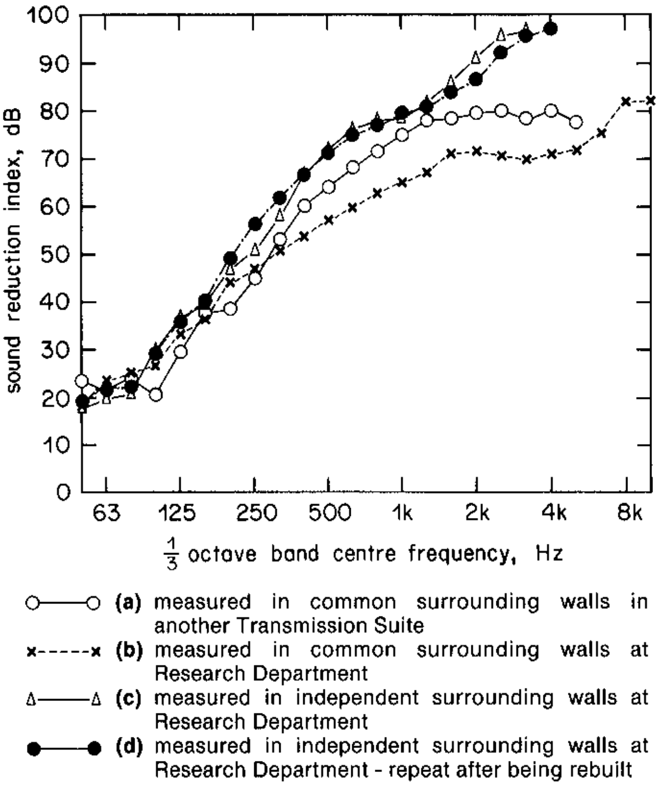


Fig. 2 - The measured sound insulations of a metal-framed, double leaf partition.

The sound insulation curve for the test, with the two leaves built into common surrounding walls, was considerably lower when the partition was built in the Research Department Transmission Suite, rather than in the different Transmission Suite. No flanking paths were observed for leakage of sound through the surrounding building structure of the Research Department Transmission Suite; also, the sound insulation of the test partition, with both leaves built into common surrounding walls, was at least 10 dB lower, at all frequencies, than the previously-measured[3] upper limit for the sound insulation performance of the Transmission Suite (with a cavity brick wall built into the receive room walls).

The measured airborne sound insulation was lower when the two leaves of the test partition were built into one surrounding wall rather than two. Initially, this was thought to be because the two leaves of the partition were mechanically coupled at the perimeter of the test partition. The cause of the difference between the Research Department measurement and the different Transmission Suite measurement, with the leaves of the partition built into common surrounding walls, was then attributed to the different mounting conditions (and hence the degree of coupling) for the two tests. (The size and shape of a partition will have an effect on the airborne sound insulation, whether the partition has single or multiple leaves[4]. However, the degree of coupling between the leaves of multiple leaf partitions may also depend upon the size and shape of the test partition, and the mounting conditions at the perimeter of the partition.) In this case, before a check could be made for the validity of attributing the shortfall in the sound insulation to mechanical coupling at the perimeters of the leaves of the partition, vibration isolation measurements had to be made on the partition.

3. VIBRATION ISOLATION MEASUREMENTS

The vibration isolation was measured between the two leaves of the test partition, in the Research Department Transmission Suite, to investigate the nature of any coupling between the two leaves. The measurements were made with the two leaves built into either common surrounding walls or into independent walls.

3.1 Acceleration-acceleration isolation measurements

To investigate how the degree of coupling varied over the area of the partition, the vibration isolation was measured on a grid of 48 equally spaced positions (a rectangular array of 6 by 8 positions). For each position, the acceleration on the source room side of the partition was measured, and at the same time, the acceleration was measured at the same position on the receive room side of the partition. The source room side of the partition was struck several times with a small hammer near the accelerometer position and the peak ⅓rd octave acceleration spectra were measured. (Hammer impacts were used as the source, rather than airborne noise from a loudspeaker, as impact isolation measurements give much better coherence between the two accelerometer signals[5].)

3.1.1 Contour plots

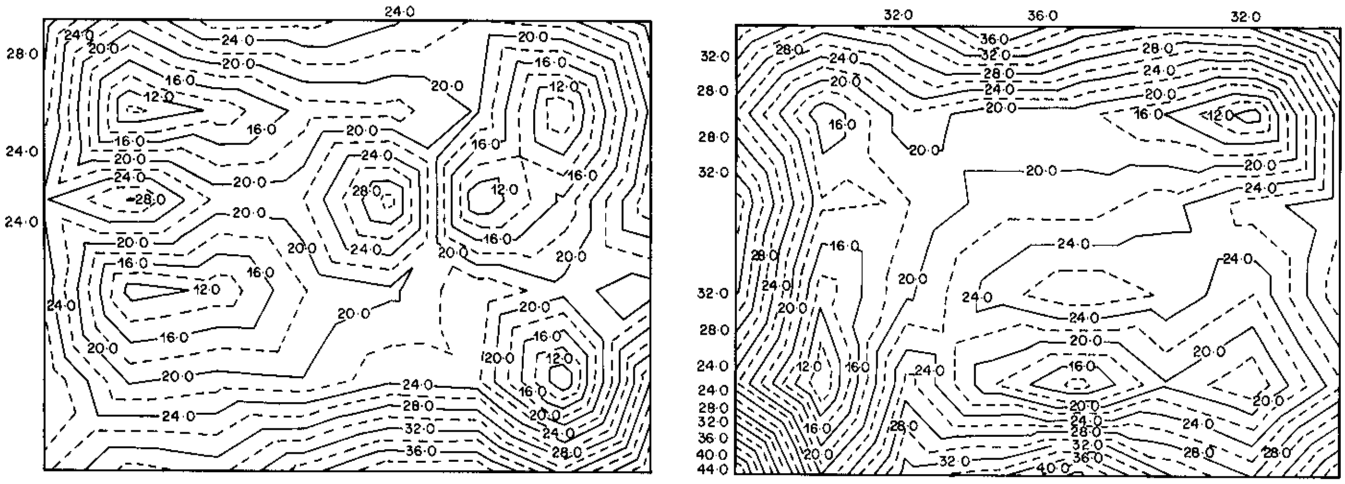
Contours were plotted of the acceleration-acceleration isolation values, in each ⅓rd octave frequency band from 50 Hz to 10 kHz. These plots were for the two leaves of the test partition built either into common surrounding walls, or into independent surrounding walls. There were thus 48 contour plots. This amount of information is difficult to portray in its entirety in a comprehensible manner. Contour plots of single figure values for the average isolation at each measurement point (over all frequencies) would not be very meaningful, as the variation in the isolation contours with frequency would not be shown. Therefore, the isolation contours for the measurements at 80 Hz, 400 Hz and 2 kHz will be considered (these isolation contours were typical of the others measured at low, mid and high frequencies respectively).

Figs. 3 - 5 show the acceleration-acceleration isolation contours over the partition, at 80 Hz, 400 Hz and 2 kHz. There are localised 'hot spots' in the contours where the isolation values change quite sharply (this may have been caused by some non-uniformity in the construction of the partition), but the significance of the results lies in the gradual change in the isolation contours from the centre of the partition to its perimeter.

At 80 Hz (Fig. 3), the average isolation at the centre of the partition (predominantly by the air in the cavity between the two leaves of the partition) was less than the mechanical isolation at the perimeter of the partition (whether the partition was built into common or independent surrounding walls). The level of isolation at the perimeter was less when the partition was built into common, rather than independent, surrounding walls (as expected). Consequently, the isolation at the centre of the partition was less when the two leaves of the partition were built into common surrounding walls; this is because the effective level of isolation at the centre of the partition is dependent upon the level of mechanical isolation at the perimeter. With both leaves of the partition built into common surrounding walls, a proportion of the energy transmitted from the centre of one leaf to the centre of the other, followed a path via the perimeter of the partition, rather than directly through the cavity between the two leaves.

At 400 Hz (Fig. 4), when the partition was built into common surrounding walls, the isolation at the centre of the partition (mostly by the air in the cavity between the two leaves of the partition) was greater than the mechanical isolation at the perimeter of the partition. However, when the two leaves of the partition were built into independent surrounding walls, the isolation was approximately the same at the centre and at the perimeter of the partition. The level of mechanical isolation at the perimeter was considerably less when the partition was built into common, rather than independent, surrounding walls. As at 80 Hz, the isolation at the centre of the partition depended upon the level of isolation at the perimeter, and was much lower when the two leaves of the partition were built into common surrounding walls.

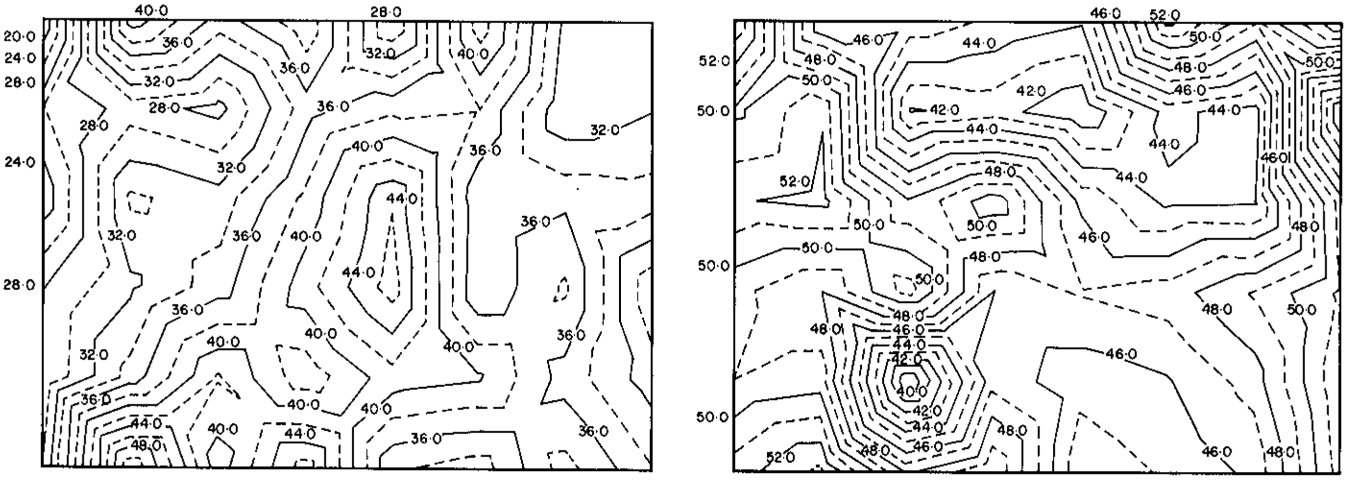
At 2 kHz (Fig. 5), when the two leaves of the partition were built into independent surrounding walls, the level of isolation at the centre of the partition (by the air in the cavity) was similar to the level of mechanical isolation at the perimeter of the partition. However, when the partition was built into common surrounding walls, the isolation at the centre of the partition was greater than the mechanical isolation at the perimeter of the partition. The mechanical isolation at the perimeter was less when



(a) *Partition in common surrounding walls*

(b) *Partition in independent surrounding walls*

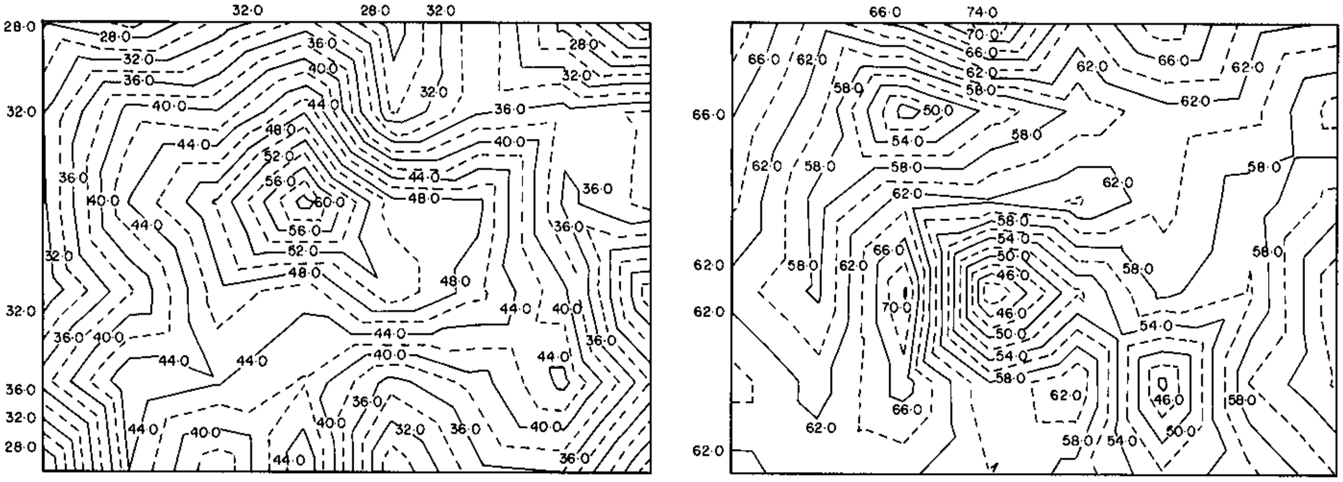
Fig. 3 - Contour plots of acceleration-acceleration isolation (dB) at 80 Hz.



(a) *Partition in common surrounding walls*

(b) *Partition in independent surrounding walls*

Fig. 4 - Contour plots of acceleration-acceleration isolation (dB) at 400 Hz.



(a) *Partition in common surrounding walls*

(b) *Partition in independent surrounding walls*

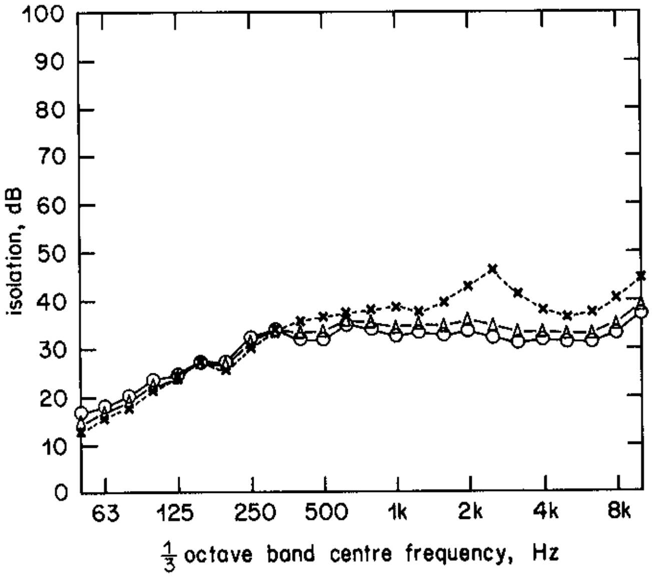
Fig. 5 - Contour plots of acceleration-acceleration isolation (dB) at 2 kHz.

both leaves of the partition were built into common surrounding walls, rather than independent walls. As at 400 Hz, the effective level of isolation at the centre of the partition depended upon the level of isolation at the perimeter; the centre isolation was less when the two leaves of the partition were built into common surrounding walls.

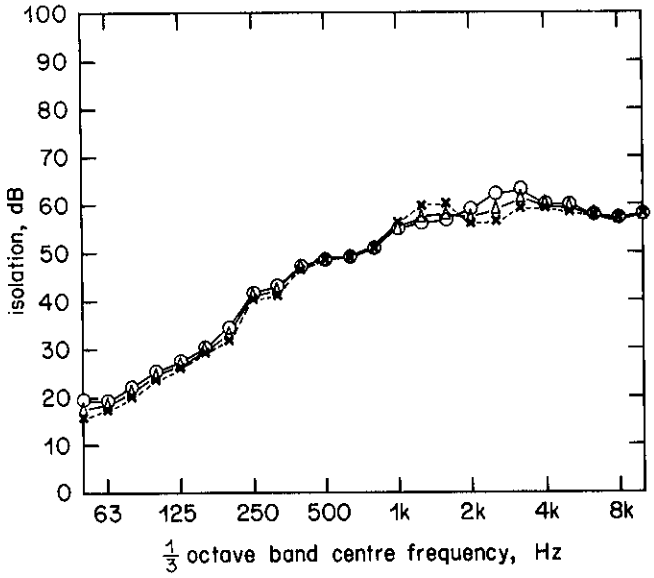
3.1.2 Centre and perimeter isolations

Software was written to evaluate representative values for the centre and perimeter isolations in each ⅓rd octave frequency band. Estimates were made of the isolations at 480,000 equally spaced points on the surface of the partition, by linear interpolation between the isolations at the 48 measurement points (to multiply the number of points in the vertical direction by 100, and similarly for the number of points in the horizontal direction). The mean of the isolations, at all interpolated points that were within 0.6 m of the boundary of the partition, was used as an estimate of the perimeter isolation. The estimate of the centre isolation, was the mean of the isolations at all points that were not closer than 0.6 m to any of the boundaries of the partition. An estimate was also made of the overall isolation of the partition, by evaluating the mean of the isolations at all of the interpolated points on the partition. The isolations were converted to linear form and inverted before averaging, to give a reasonable estimate of an average based on sound power flow into the receive room, for a constant excitation in the source room.

The calculated centre, perimeter and overall isolations are plotted in Fig. 6(a), for the two leaves of the partition built into *common* surrounding walls; Fig. 6(b) shows the corresponding curves for the situation with each leaf of the partition built into a *separate, independent* surrounding wall. For the case of the two leaves of the partition built into common surrounding walls, the perimeter isolation is greater than the centre isolation up to 315 Hz; above this frequency, the perimeter isolation is significantly lower than the isolation at the centre of the partition. With the two leaves of the partition built into independent surrounding walls, the isolation at the perimeter of the partition is slightly higher than the isolation at the centre of the partition up to 400 Hz; above this frequency, neither isolation is consistently higher than the other. With the two leaves of the partition built into common surrounding walls, the centre and perimeter isolations up to 160 Hz are similar to, but marginally less than, the corresponding isolations when the two leaves were built into independent surrounding walls. Above this frequency the differences become much larger. With the two leaves of the partition built into common surrounding walls, the acceleration-acceleration isolation tends to a constant value above 250 Hz; this effect is often observed in vibration isolation systems where anti-vibration mountings have been partially bridged.



(a) Both leaves of the partition built into common surrounding walls.



(b) Each leaf of the partition built into a separate, independent surrounding wall.

O——O perimeter isolation
×-----× centre isolation
Δ——Δ whole isolation

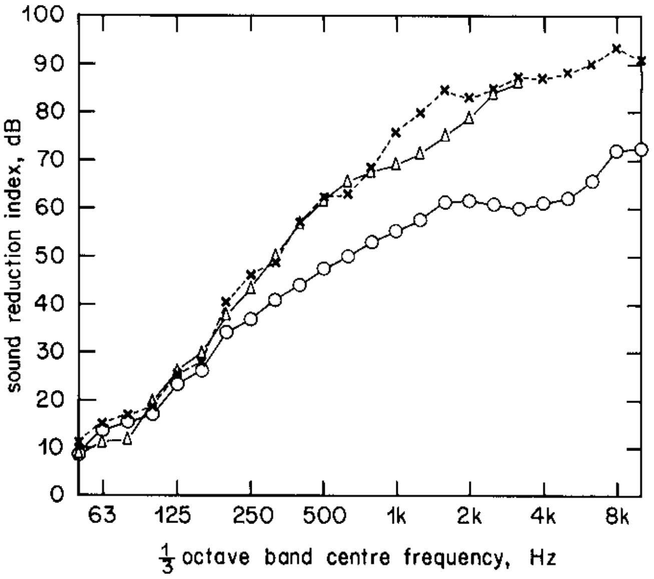
Fig. 6 - Acceleration-acceleration isolation measurements.

Note that the perimeter isolations are not as large as initially might be expected, having studied the contour plots. This is because the edge isolation is a power average over all points within 0.6 m of the perimeter of the partition. This area of the partition was considered to be representative, as the contours showed most change over this area.

3.1.3 Prediction of the airborne sound insulation from vibration measurements

A prediction was made from these vibration isolation measurements, of the difference between the measured airborne sound insulation, when the two leaves of the partition were built into independent surrounding walls, and the insulation when the two leaves were built into common surrounding walls. The mean vibration isolation at each frequency, for both partition mounting conditions, was calculated (as described in Section 3.1.2) by integrating the acceleration-acceleration isolation measurements (as the sum of the power ratios) over the whole area of the partition. The differences (in dB terms), in each frequency band, between the integrated isolations for each partition mounting method, give an estimate of the differences between the airborne sound insulations for each mounting method.

In Fig. 7, the difference between the vibration isolation measurements, for the two partition mounting conditions, has been added to the airborne sound insulation of the partition with both leaves built into common surrounding walls; this gives a prediction of the airborne sound insulation with each leaf of the partition built into an independent surrounding wall **(b)**. This prediction is compared with the measured sound insulation when the two leaves were built into common surrounding walls **(a)**; it is also compared with the average of the two measurements when the two leaves were built into independent surrounding walls **(c)**.



○——○ **(a)** measured in common surrounding walls
×- - - -× **(b)** calculated from acceleration-acceleration isolations in common and independent surrounding walls
Δ——Δ **(c)** average of both measurements in independent surrounding walls

Fig. 7 - The sound insulations of a metal-framed, double leaf partition.

The predicted sound insulation curve agrees very well with the average of the measured sound insulations of the partition having two leaves built into independent walls. The only significant differences between the curves occur between 1 kHz and 1.6 kHz. The differences may have arisen because there was some unidentified flanking path when the sound insulations were being measured, or the differences may have arisen because some of the assumptions made in the prediction may not be valid.

3.2 Force-acceleration isolation measurements

Measurements of the accelerations on either side of the partition (to give an acceleration-acceleration isolation measurement) should give a good indication as to whether the two leaves of the partition are mechanically coupled to each other at any point. However, the relationship between the force applied to the source room side of the test partition and the acceleration of the receive room side of the partition (to give a force-acceleration isolation measurement), is more relevant when the mechanism of airborne sound transmission is considered. This is because, for airborne transmission, the sound pressure level in the source room produces a distributed force over the partition, which determines the level of vibration in the source room leaf of the partition. When the vibration has been transmitted through the partition, it is the vibration of the receive room side of the partition that determines the sound pressure level generated in the receive room. Measurement of the force-acceleration isolation might give a closer prediction of the shortfall in sound insulation, caused by building the two leaves of the partition into common surrounding walls.

To realise this more representative test*, the force impinging on the source room side of the partition, was measured with an accelerometer screwed to the back face of a sledgehammer. The sledgehammer was used to strike the partition at each of the 48 measurement points, with the two partition leaves built either into common surrounding walls, or into independent walls (the accelerations of the corresponding points on the receive room side of the partition were also measured). The force applied is proportional to the acceleration of the hammer (Newton's Second Law of Motion).

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* An even more representative measurement would be the relationship between the force applied to the source room side of the partition and the resultant sound pressure level in the receive room, for each measurement point. This is because striking the source room side of the partition makes all of the receive room side of the partition vibrate, and it is the summation of the vibration over all of the receive room side of the partition that determines the sound pressure level generated in the receive room. However, this measurement was not performed, as the impact force and the receive room sound pressure level are not very closely linked; so the bridging of the leaves of the partition would probably not have shown up as well as for the other measurement described.

3.2.1 Contour plots

Figs. 8-10 *(overleaf)* show the force-acceleration isolation contours over the partition at 80 Hz, 400 Hz and 2 kHz. As before, contours are plotted for both leaves of the partition built into common surrounding walls, and for each leaf of the partition built into independent surrounding walls. The contour plots show similar features to those for the acceleration-acceleration isolation measurements. It is not intended to discuss the results in any detail, as most of the comments that were given for the acceleration-acceleration isolation contours also apply here.

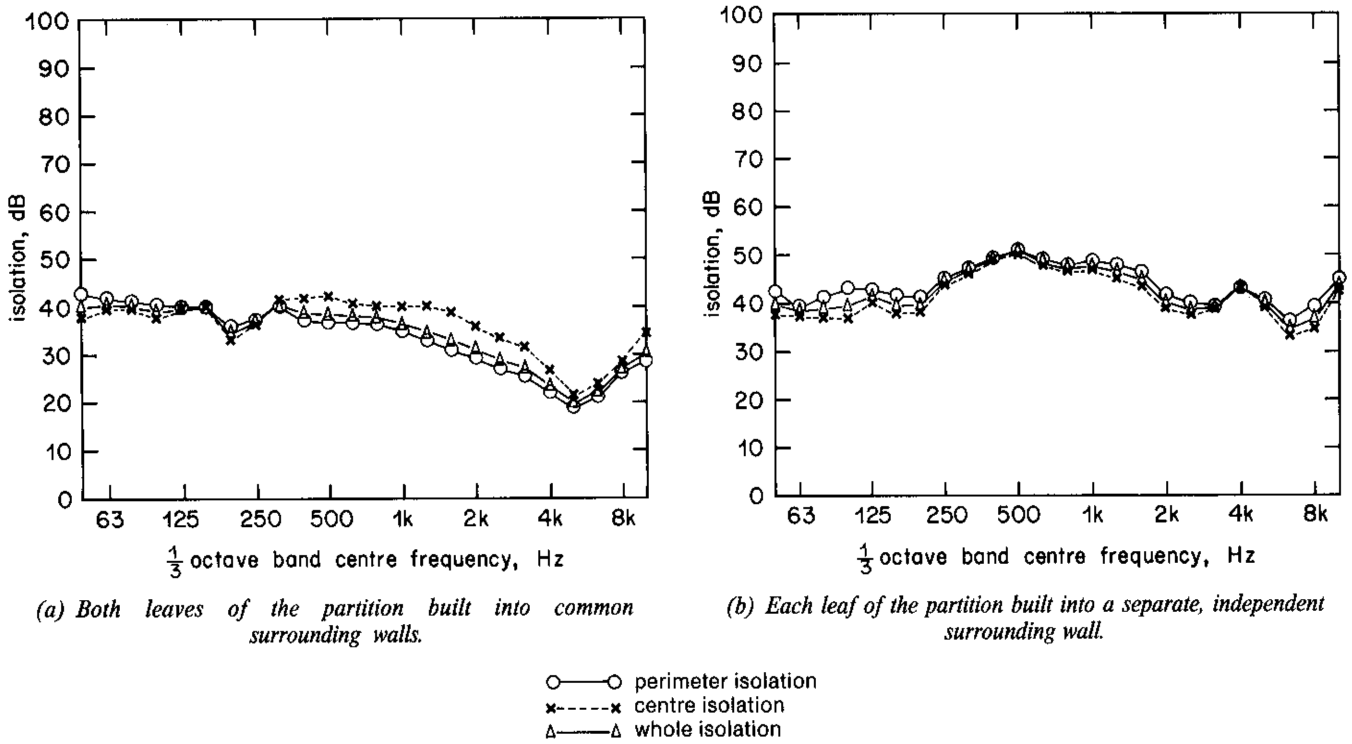
3.2.2 Centre and perimeter isolations

The centre, perimeter and overall isolations are shown in Fig. 11(a) for the situation when two leaves of the partition were built into *common* surrounding walls. Fig. 11(b) shows the corresponding curves for both leaves of the partition built into *separate, independent* surrounding walls. When the two leaves of the partition were built into common surrounding walls, the perimeter isolation was greater than the centre isolation up to 250 Hz. Above this frequency, the isolation at the perimeter of the partition was significantly lower than the centre isolation. When the two leaves of the partition were built into independent surrounding walls, the perimeter isolation was slightly higher, at all frequencies, than the isolation at the centre of the partition; hence the isolation at the centre of the partition was relatively unaffected by the isolation at the perimeter of the partition.

When the two leaves of the partition were constructed in common surrounding walls, the centre and perimeter isolations, up to 160 Hz, were comparable with the corresponding isolations for the situation when the two leaves were constructed in independent surrounding walls. The differences become much larger above this frequency.

3.2.3 Prediction of the airborne sound insulation from vibration measurements

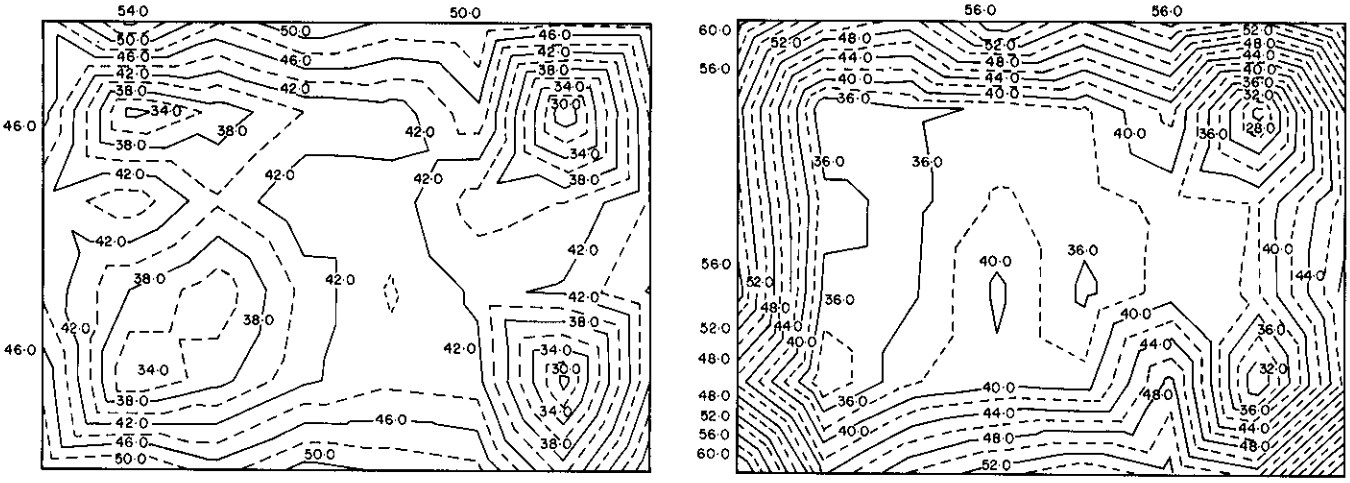
As with the acceleration-acceleration isolation measurements, a similar prediction can be made from these force-acceleration isolation measurements. The prediction is for the difference between the airborne sound insulations, when the two leaves of the partition were built either into independent surrounding walls or common surrounding walls. The calculation would only be an estimate of the difference, because the sound pressure level would not usually be constant over the surface of the source room side of the partition, when measuring airborne sound insulation.



(a) Both leaves of the partition built into common surrounding walls.

(b) Each leaf of the partition built into a separate, independent surrounding wall.

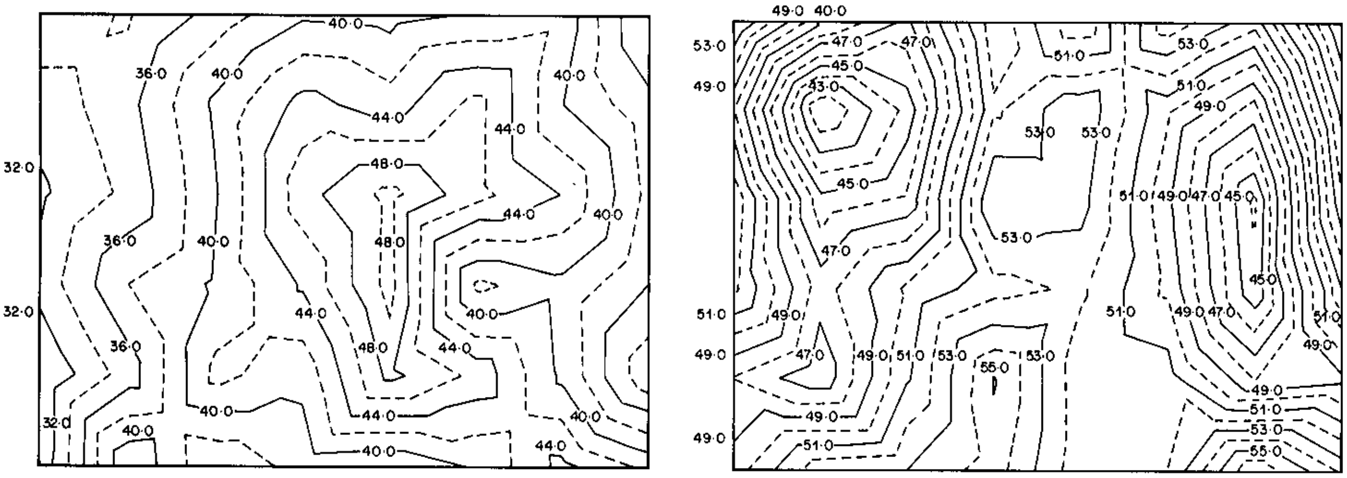
Fig. 11 - Force-acceleration isolation measurements.



(a) Partition in common surrounding walls

(b) Partition in independent surrounding walls

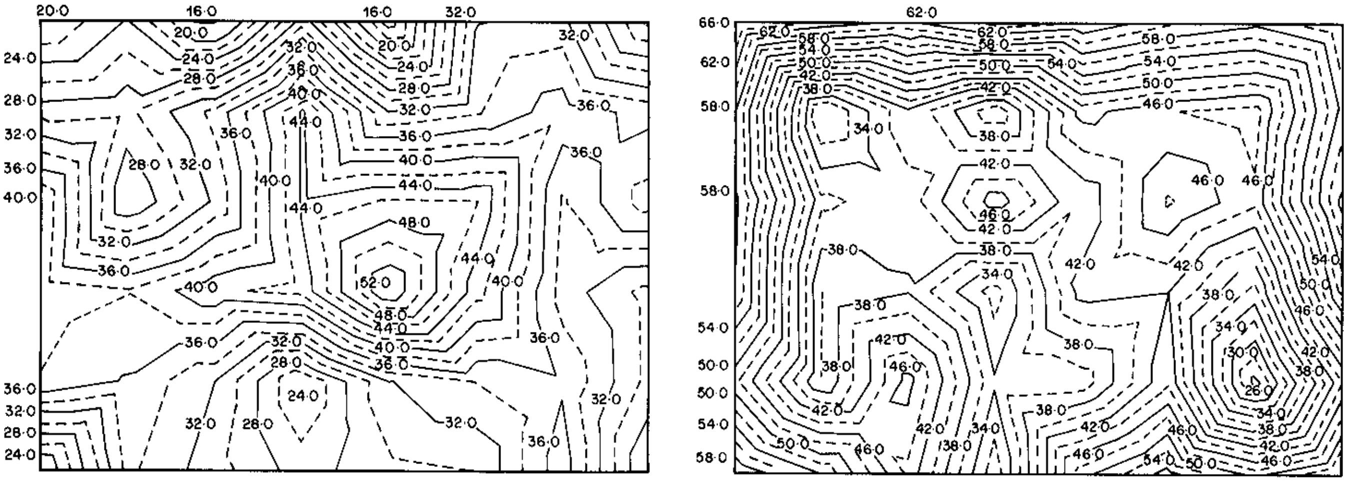
Fig. 8 - Contour plots of force-acceleration isolation (dB) at 80 Hz.



(a) Partition in common surrounding walls

(b) Partition in independent surrounding walls

Fig. 9 - Contour plots of force-acceleration isolation (dB) at 400 Hz.



(a) Partition in common surrounding walls

(b) Partition in independent surrounding walls

Fig. 10 - Contour plots of force-acceleration isolation (dB) at 2 kHz.

A more representative prediction of the airborne sound insulation is given by the integrated sum of the differences between the force applied by hammer impacts, at different points on the source room side of the partition, and the resultant average sound pressure level in the receive room.

Fig. 12 shows the prediction of the airborne sound insulation with each leaf of the partition built into an independent surrounding wall, which was derived from the force-acceleration isolations. The predicted sound insulation agrees fairly well with the average of the measured sound insulations when the two leaves of the partition were built into independent walls. Significant differences exist between the curves from 630 Hz to 800 Hz, and above 1.6 kHz. The differences may have been caused by some inaccuracy in the assumptions made in the prediction. However, at higher frequencies, there were some difficulties with the level of background noise, when making the force-acceleration isolation measurements. This may have been why the predicted sound insulation was lower than the measured sound insulation at higher frequencies.

In practice, the acceleration-acceleration isolation proved to be much easier to measure. However, the force-acceleration isolation value is a more representative value when the mechanism involved in sound transmission through the partition is considered. It is, therefore, advisable to adopt the force-acceleration measurement method, when making measurements of the isolation between the leaves of similar partitions in the future. Nevertheless, care will have to be taken to minimise the effects of background noise on the measured isolations.

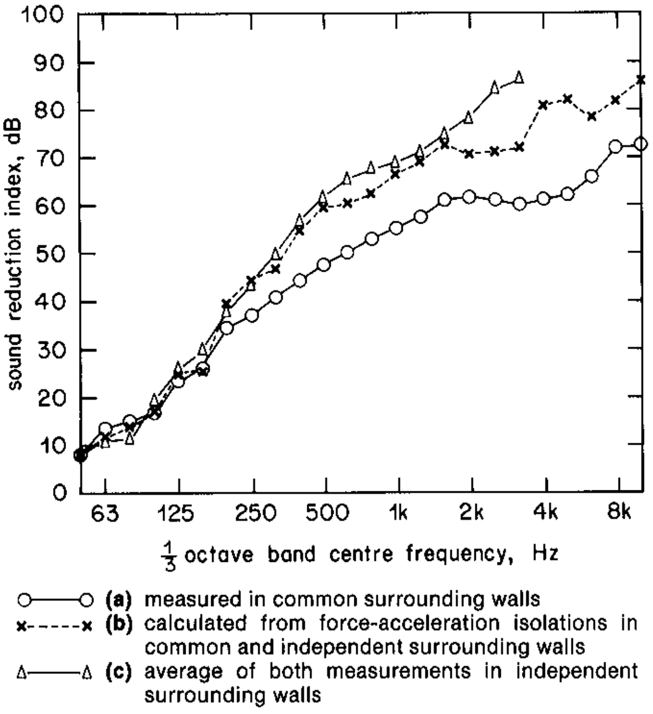


Fig. 12 - The sound insulations of a metal-framed, double leaf partition.

4. CONCLUSIONS

The airborne sound insulation of a particular type of double leaf partition, with the two leaves built into common surrounding walls, was less when measured in the Research Department Transmission Suite, rather than in a different Transmission Suite; but the previously mentioned sound insulation, when the leaves were built into common surrounding walls in the different Transmission Suite, was less than the sound insulation with the two leaves of the partition built into independent surrounding walls in the Research Department Transmission Suite. It is possible that neither measurement, in the Research Department Transmission Suite, agrees with the measurement in the different Transmission Suite because, in the different Transmission Suite test, the other mounting conditions were dissimilar (the partition size and shape, and the details of the frame in which the partition was mounted, were dissimilar).

Contour plots of the vibration isolations between the two leaves of the partition, with the leaves built into either common or independent surrounding walls, revealed the level of mechanical isolation at the perimeters of the leaves. With both leaves of the partition built into common surrounding walls, estimates of the vibration isolations at the centre and perimeter of the partition, showed that the mechanical bridging was only significant at higher frequencies. With each leaf of the partition built into an independent surrounding wall, the mechanical bridging at the perimeter of the partition was insignificant. An estimate was made, from the vibration isolation measurements, of the difference between the overall vibration isolation of the partition for two separate constructions (i.e. the isolation with the leaves built into common surrounding walls, and the isolation with each leaf built into independent surrounding walls). This gave a good prediction of the difference between the airborne sound insulations of the partition for the two mounting conditions.

Transmission Suite measurements, with the leaves of multi-leaf partitions built into independent surrounding walls, will be appropriate for predicting the sound insulations of partitions in the field, when the predominant mechanism for coupling between the leaves in the field installation is by the air in the cavities between the leaves. These Transmission Suite measurements will also be useful when predicting the field performances of large, multi-leaf partitions, which have a relatively small proportion of mechanical coupling between the leaves in comparison to their surface area. Such Transmission Suite measurements will presumably be more reproducible than measurements with the leaves built into common surrounding walls (measurements will probably be more dependent on the nature of the boundary constraints and the size and shape of the partition, when the partition is built into common, rather than independent, surrounding walls).

The measurements described in this Report demonstrate the levels of reduction in the airborne sound insulations of multi-leaf partitions that can result from coupling of the leaves. This effect is already well known, but the results demonstrate the need for truly independent leaves in multi-leaf partitions.

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